Influence of Inter-electrode Distance on EMG

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Abstract –

This paper reports experimental research undertaken to study the effect of variation of inter-electrode distance on the Electromyogram (EMG). The experiments were conducted on ten healthy subjects and they performed isometric contraction of their biceps of the right arm at 20, 50 and 80% of their maximal voluntary contraction (MVC). EMG was recorded using surface electrodes with the distance between the two active electrodes being 18 and 36mm. It has been observed that at low levels of muscle contraction there was no significant variation due to the change in the distance between the electrodes while at 50 and 80% of MVC there was a significant change in the amplitude of the EMG. Using Time- Frequency analysis of EMG, the study demonstrates a variation of the spectral content of the EMG with change in the IED. The study also has shown that there is a variation of the EMG with muscle contraction but that the comparison should be done if the distance between the electrodes has been kept constant.

Key Words: Inter-electrode distance, RMS, Time-Frequency.

I. INTRODUCTION

EMG signal is a result of the summation of all the Motor Unit Action Potentials (MUAP) in the region of the electrodes. MUAP are inherently random, non-stationary, and the electrical characteristics of the surrounding tissues are non-linear. Thus EMG is a very complex signal. The amplitude of the EMG recorded from the surface (non-invasive) ranges from peak-to-peak 0 to 10mv or Root Mean Square (RMS) value ranging between 0 to 1.5mv, is stochastic in nature. Distribution of the EMG can be approximated by a Gausian function [1].

EMG is used for a number of applications including prosthesis control [3,4], muscle diagnostic and biofeedback. Vineet and Reddy [2] observed a linear relationship between RMS of EMG and the finger flexion-extension – suggesting the use of EMG for bio-control for anthropomorphic tele-operators and Virtual Reality entertainment. EMG amplitude and frequency have also been investigated as indicators of localized muscular fatigue. Amplitude and spectral information of EMG have also been exploited to estimate force of muscle contraction and torque [5].

EMG may be affected by various factors. The anatomical/ physiological processes such as properties and dimensions of tissues, and force and duration of contraction of the muscle are known to influence the signal. The peripheral factors such as spacing, type and size of electrodes may also have an influence on the signal and to obtain reliable information, considering such factors is critical [1]. Some of these factors may be handled through careful detection techniques, but not all these factors can be easily controlled and is daunting and complex [1].

In the past some researchers have attempted to determine the effect of some peripheral factors on EMG recordings. Gerdel et al [4] conducted experimental research and determined that there was no change in the mean power frequency-force relationship or any change in the mean power frequency (MPF) during fatigue inducing activity due to a variation in the Inter Electrode Distance (IED). Zedka et al [6] have analyzed the amplitude and MPF of the EMG and have observed an increase in MPF with increase in IED. Roberto et al [7] investigated, using simulation techniques, the effect of inter-electrode distance on Average Rectified Value and determined that the amplitude of the signal decays rapidly with increasing depth of the active muscle fibers for smaller values of inter-electrode distance. By using a model for Motor Units, Fugelvand et al [10] simulated EMG and determined that IED can modify the amplitude of EMG.

The above demonstrates that there are disagreements related to the effect of IED on the EMG recording. Hogrel et al [11] have suggested that lack of standardization on the anatomical sites and methodology to record EMG as the cause for the contradictory results. Moritani and Muro [5] have partially explained some of the inconsistencies and variability based on the muscle type as well as electrode orientation.

This paper reports the experimental research undertaken to characterize the RMS/ amplitude of EMG based on the IED and the load the muscle has to support. The experiments were controlled and this included the choice of subjects, anatomical site, choice of electrodes. The experimental protocol was standardized to ensure that the only variation between different recordings was IED or % Maximum Voluntary Contraction (MVC).

II. EMG

Muscle contraction is a result of electrical stimulation received from the nerves to individual muscle fibers. This results in electrical activity that can be recorded by electrodes kept in the close proximity of the muscles. This recording is called EMG. The signal is a summation of number of motor unit action potentials that are spatially and temporally separated. The signal is complex and non-stationary, it is bi-phasic and cannot be represented by a simple mathematical function.

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The force produced by contraction of muscles depends on the number of active muscle fibers and the rate of activation of these fibers. Zero- crossing and spectral analysis provide an indication of the rate of activation of the muscle fibers and the density of muscle fibers that are being activated. The amplitude of EMG is an indicator for the size of active motor units and the integrated EMG and the RMS–EMG are indicators of rate (density) of activation as well as the number of active motor units and the size of these motor units. Thus RMS of EMG highlights the 'strength of the signal' and thus the strength of contraction of the muscle and is a very popular technique.

A. RMS-EMG:

RMS of the signal is an indicator of the amplitude trend and density of the signal. It thus is a good indicator for the 'strength of EMG'. Given the EMG signal, $S(n)$, a function of time, to compute the RMS of the EMG, $A(n)$, consider a smoothing window of length L [15]. The RMS of the signal is:

$$A[n] = \left[\frac{1}{L} \sum_{n-L+1}^{i=n} s^2[i] \right]^{1/2} \quad \textbf{(1)}$$

The window length is an important parameter for computing the RMS of the signal. The choice is dependent on the signal spectrum properties. By varying the length of the window from 24 to 500ms, Denis et al [15] investigated the effect of the length of the window on the computed RMS of EMG. They assumed that the muscle activity was constant during the recording and were able to demonstrate that a longer smoothing window length can significantly increase the Signal to Noise ratio (SNR) performance. But a very large window would average the signal over time and all the variation with time information would be lost. Thus the choice of the window is a trade off between SNR and frequency of changes in the muscle contraction.

III. METHOD

A. Experiment:

The experiment were controlled and designed in such a way to reduce variations but for the variations being studied- that is - the distance between the electrodes and the level of muscle contraction. The subject were volunteers and were asked to perform isometric elbow flexion. The force produced was measured using a load cell and recorded along with the EMG. There were three active electrodes used- one common while one was at 18mm and the other at 36 mm. The location of the three electrodes for recording the EMG was selected to be parallel and above the innervation point of the muscle biceps brachii. Two inter-electrode distances were chosen -18 and 36mm. To maintain consistency of results, the location of electrodes was marked using a marking pen. The ground electrode was near the elbow and was not changed during the experiment.

To ensure that the results were accurate, the MVC of the subjects was carefully measured. The MVC of each of the volunteers was measured using the recordings of force using the load cell and averaged over three readings. Based on the value of the MVC, 20%, 50% and 80% load levels were computed. Subjects were instructed to perform isometric elbow flexions at the three assigned contraction levels seated in a position with the forearm semi-pronated and 90 degrees of forward flexion in the shoulder and with the elbow resting on the table. Subjects were then asked to maintain muscle contraction at 20%, 50% and 80% for 10 seconds and were assisted using feedback of the force of contraction they generated. EMG was recorded during this period. EMG and force of contraction were recorded to verify that the muscle contraction was stable during the recording period.

Signals from the amplifier and the transducer were acquired simultaneously on a personal computer equipped with AMLAB software for data acquisition. All signals were amplified and sampled with a rate of 5Khz. To minimise movement artefacts and aliasing, a band-pass filter was used. A notch filter was used to reduce power-line interference.

The experiment was repeated for 10 healthy subjects- 5 males and 5 females in the age group of 19 to 34 years. All the subjects chosen were 'right handed'.

There were six recordings- 3 for IED 18mm and 3 for 36mm for each subject. The three recordings for each IED corresponded with 20%, 50% and 80% MVC. For all the experiments, the Swaromed make, 'Universal' type and 10 mm diameter were used.

B. Analysis:

After the signals was recorded, the analysis was performed off-line using MATLAB. Using a time window of length 500 samples, RMS was computed. The RMS was then averaged for each recording. The results were tabulated. The Time Frequency (TF) analysis was conducted using WVD and ZAM to study the spectral content of the signal and the difference due to the change in IED.

Table 1 has 4 columns- load % MVC, range of load as measured, value of RMS of the signal for the two IED. Each sub-table corresponds with a specific subject. This table was completed for each of the 10 subjects and the eleventh table corresponds to the mean for all the subjects. The results from this table help to determine the influence of IED on RMS-EMG.

Table 2 and table 3 are the descriptive statistics of the results. is for determining the influence of load on the RMS-EMG. This table provides statistical information of the frequency of the EMG with respect to the %MVC and IED.

IV. RESULTS

The sample results of the above experiment are shown in Figures 1,2 and 3. All these results are for subject #1.

Table 1: Evaluated RMS-EMG values for the ten subjects

Subject#1

MVC (%)	Force (Newton)	Rms-EMG (mV) IED=1.8Cm.	Rms-EMG (mV) IED=3.6Cm.
20	30-32.1	0.0004	0.0010
50	67.4-68	0.0015	0.0021
80	103-107	0.0037	0.0057

Subject#2

20	29-31	0.0088	0.0046
50	68-71	0.0063	0.0079
80	109-109	0.0096	0.0147

Subject#3

20	9.8-10.3	0.0087	0.0088
50	23-24	0.0035	0.0088
80	39-40	0.0071	0.0112

Subject#4

20	41-41.8	0.0055	0.0094
50	83-84.8	0.0131	0.0214
80	126-130	0.0238	0.0430

Subject#5

20	31-32.7	0.0092	0.0079
50	80-80.6	0.0143	0.0198
80	129-130	0.0271	0.0536

Subject#6

20	23-26	0.0047	0.0047
50	64-65	0.0091	0.0175
80	107-108	0.0105	0.0271

Subject#7

20	17-21	0.0130	0.0034
50	47-53	0.1397	0.0095
80	68-74	0.0120	0.0145

Subject#8

20	21-21.5	0.0003	0.0035
50	53-53.8	0.0005	0.0045
80	82-85	0.0011	0.0060

Subject#9

20	12-13.8	0.0024	0.0026
50	29-30	0.0041	0.0052
80	54-55	0.0080	0.0092

Subject#10

20	13.4-13	0.0016	0.0018
50	32-32.3	0.0034	0.0048
80	60-61	0.0054	0.0092

Figure 1 is a recording at 20% MVC, Figure 2 for 50% MVC and figure 3 of 80% MVC. Table 1 is used to depict the values of the RMS of EMG while Table 2 and 3 show the results of a descriptive statistics. Since the result from subject #7 showed high inconsistency and almost no significant pattern, it was omitted from the statistical analysis

From Table 1 and 2 it is observed that the RMS-EMG amplitude increases as the force level increases. The amplitude monotonically increases going from 20 to 80% of MVC. This trend or pattern is consistent irrespective of the value of IED.

The statistical analysis of the results (table 2 and 3) with the RMS averaged over the 9 subjects demonstrates a monotonic increase of the RMS with the increase in the level of muscle contraction. It is also observed that the value of the RMS of the EMG at 36mm is higher compared with the value at 18mm for each of the levels of muscle contraction. Further, it is also observed that the standard deviation of the RMS increases with the increase in the level of muscle contraction as well as with the increase in IED.

%MVC	IED	RMS-EMG :Mean		Std. Deviation
		Statistic	Std. Error	Statistic
20	18mm	0.0046	0.0012	0.0036
20	36mm	0.0049	0.0010	0.0039
50	18mm	0.0062	0.0016	0.0049
50	36mm	0.0102	0.0024	0.0073
80	18mm	0.0107	0.0029	0.0088
80	36mm	0.0199	0.0058	0.0174

Table 2: Descriptive statistics

	(IED=18mm)		(IED=36mm)		Average (B+C)/2
% MVC	Mean -RMS	Std. Dev-RMS	Mean-RMS	Std. Dev-RMS	
20	0.0046	0.0036	0.0049	0.0039	0.0048
50	0.0062	0.0049	0.0102	0.0073	0.0082
80	0.0107	0.0088	0.0199	0.0174	0.0153

Table 3: Descriptive statistics

The TF analysis of EMG suggests that with smaller IED, the recorded EMG has higher frequencies content. It is also observed that the mean frequency increases from 20 to 50% MVC. This pattern was consistent irrespective of IED, however, mean values at 18mm were higher than at 36mm.

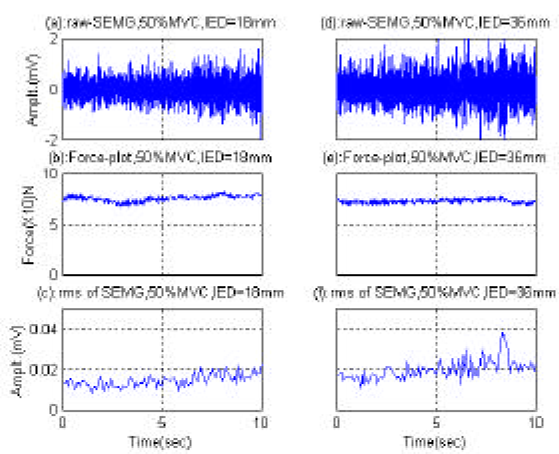

Figure 2: Plots of raw-EMG (a &d), force (b&e) and RMS of the signal (c&f) at 50% of MVC with IED 18 and 36mm

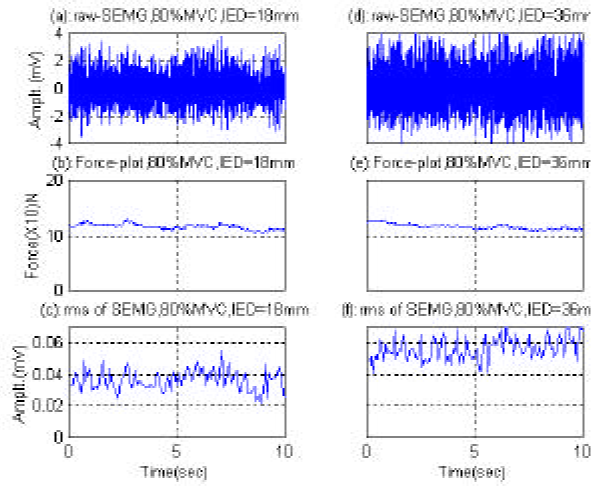

Figure 3: Plots of raw-EMG (a &d), force (b&e) and RMS of the signal (c&f) at 80% of MVC with IED 18mm and 36mm

V. CONCLUSION

From Table 2, it is observed that the sample mean for RMS-EMG for 20 % is lower than for 50% for both, 18mm and 36 mm IED. It is also observed that the sample mean for RMS-EMG for 50% is lower than that of 80%. This demonstrates that there is an increase in the RMS-EMG with increase in the %MVC.

From Table 3, it is observed that for all the three levels of muscle contraction, there is an increase in the value of the RMS-EMG with the increase in the IED, for 36 mm the sample mean being 0.0049, 0.0102 and 0.0199 V compared to 0.0046, 0.0062 and 0.0107 V for the 18mm IED.

This research demonstrates that there is a significant variation of RMS- EMG by changes of muscle contraction and inter-electrode distance. There is an increase in the magnitude of the RMS of EMG with an increase in the inter-electrode spacing. This observation was consistent for all experimental participants except one subject exhibiting inconsistency. It may be, therefore, concluded that IED has a significant influence on the RMS of EMG.

Clinicians and researchers often use RMS and zero crossing/ frequency content as indicators of the strength of contraction of the muscles. This paper confirms that there is a significant increase in the RMS value of EMG when the muscle is made to support a larger load- but also that there is a significant change in the RMS with the change in the inter electrodes distance.

The results also suggest that the spectral content of the signal is dependent on the distance between the recording electrodes. Based on these results, we believe that it is important for clinicians to take the IED into account when they are recording EMG. It is suggested that the distance between the electrodes should be standardised for improved reliability of EMG analysis.

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